Abstract

The present work focuses on the two areas of investigation: system identification of helicopter and design of controller for the helicopter.

Helicopter system identification, the first subject of investigation in this thesis, can be described as the extraction of system characteristics/dynamics from measured flight test data. Wind tunnel experimental data suffers from scale effects and model deficiencies. The increasing need for accurate models for the design of high bandwidth control system for helicopters has initiated a renewed interest in and a more active use of system identification. Besides, system identification is likely to become mandatory in the future for model validation of ground based helicopter simulators. Such simulators require accurate models in order to be accepted by pilots and regulatory authorities like Federal Aviation Regulation for realistic complementary helicopter mission training.

Two approaches are widely used for system identification, namely, black box and gray box approach. In the black-box approach, the relationship between input-output data is approximated using nonparametric methods such as neural networks and in such a case, internal details of the system and model structure may not be known. In the gray box approach, parameters are estimated after defining the model structure. In this thesis, both black box and gray box approaches are investigated.

In the black box approach, in this thesis, a comparative study and analysis of different Recurrent Neural Networks (RNN) for the identification of helicopter dynamics using flight data is investigated. Three different RNN architectures namely, Nonlinear Auto Regressive eXogenous input (NARX) model, neural network with internal memory known as Memory Neuron Networks (MNN) and Recurrent MultiLayer Perceptron

(RMLP) networks are used to identify dynamics of the helicopter at various flight conditions. Based on the results, the practical utility, advantages and limitations of the three models are critically appraised and it is found that the NARX model is most suitable for the identification of helicopter dynamics.

In the gray box approach, helicopter model parameters are estimated after defining the model structure. The identification process becomes more difficult as the number of degrees-of-freedom and model parameters increase. To avoid the drawbacks of conventional methods, neural network based techniques, called the delta method is investigated in this thesis. This method does not require initial estimates of the parameters and the parameters can be directly extracted from the flight data. The Radial Basis Function Network (RBFN) is used for the purpose of estimation of parameters. It is shown that RBFN is able to satisfactorily estimate stability and control derivatives using the delta method.

The second area of investigation addressed in this thesis is the control of helicopter in flight. Helicopter requires use of a control system to achieve satisfactory flight. Designing a classical controller involves developing a nonlinear model of the helicopter and extracting linearized state space matrices from the nonlinear model at various flight conditions. After examining the stability characteristics of the helicopter, the desired response is obtained using a feedback control system. The scheduling of controller gains over the entire envelope is used to obtain the desired response.

In the present work, a helicopter having a soft inplane four bladed hingeless main rotor and a four-bladed tail rotor with conventional mechanical controls is considered. For this helicopter, a mathematical model and also a model based on neural network (using flight data) has been developed.

As a precursor, a feedback controller, the Stability Augmentation System (SAS), is designed using linear quadratic regulator control with full state feedback and LQR with output feedback approaches. SAS is designed to meet the handling qualities specification known as Aeronautical Design Standard ADS-33E-PRF. The control gains have been tuned with respect to forward speed and gain scheduling has been arrived at. The SAS in the longitudinal axis meets the requirement of the Level 1 handling quality specifications in hover and low speed as well as for forward speed flight conditions. The SAS in the lateral axis meets the requirement of the Level 2 handling quality specifications in both hover and low speed as well as for forward speed flight conditions.

Such conventional design of control has served useful purposes, however, it requires considerable flight testing which is time consuming, to demonstrate and tune these control law gains. In modern helicopters, the stringent requirements and non-linear maneuvers make the controller design further complicated. Hence, new design tools have to be explored to control such helicopters. Among the many approaches in adaptive control, neural networks present a potential alternative for modeling and control of nonlinear dynamical systems due to their approximating capabilities and inherent adaptive features. Furthermore, from a practical perspective, the massive parallelism and fast adaptability of neural network implementations provide more incentive for further investigation in problems involving dynamical systems with unknown non-linearity. Therefore, adaptive control approach based on neural networks is proposed in this thesis.

A neural network based Feedback Error Neural adaptive Controller(FENC) is designed for a helicopter. The proposed controller scheme is based on feedback error learning strategy in which the outer loop neural controller enhances the inner loop conventional controller by compensating for unknown non-linearity and parameter uncertainties. Nonlinear Auto Regressive eXogenous input (NARX) neural network architecture is used to approximate the control law and the controller network parameters are adapted using updated rules Lyapunov synthesis. An offline (finite time interval) and on-line adaptation strategy is used to approximate system uncertainties. The results are validated using simulation studies on helicopter undergoing an agile maneuver. The study shows that the neuro-controller meets the requirements of ADS-33 handling quality specifications.

Even though the tracking error is less in FENC scheme, the control effort required to follow the command is very high. To overcome these problems, a Direct Adaptive Neural Control (DANC) scheme to track the rate command signal is presented. The neural controller is designed to track rate command signal generated using the reference model. For the simulation study, a linearized helicopter model at different straight and level flight conditions is considered. A neural network with a linear filter architecture trained using back propagation through time is used to approximate the control law. The controller network parameters are adapted using updated rules Lyapunov synthesis. The off-line trained (for finite time interval) network provides the necessary stability and tracking performance. The on-line learning is used to adapt the network under varying flight conditions. The on-line learning ability is demonstrated through parameter uncertainties. The performance of the proposed direct adaptive neural controller is compared with feedback error learning neural controller. The performance of the controller has been validated at various flight conditions. The theoretical results are validated using simulation studies based on a nonlinear six degree-of-freedom helicopter undergoing an agile maneuver. Realistic gust and sensor noise are added to the system to study the disturbance rejection properties of the neural controllers. To investigate the on-line learning ability of the proposed neural controller, different fault scenarios representing large model error and control surface loss are considered. The performances of the proposed DANC scheme is compared with the FENC scheme. The study shows that the neuro-controller meets the requirements of ADS-33 handling quality specifications.